Renewable and Sustainable Energy Reviews 16 (2012) 404–414

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Electric energy demands of Turkey in residential and industrial sectors

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ARTICLE INFO

Article history:
Received 16 December 2010
Received in revised form 21 July 2011
Accepted 22 August 2011
Available online 29 September 2011

Keywords:
Artificial neural networks (ANNs)
Electricity consumption
Industrial sector
Linear regression (LR)
Nonlinear regression (NLR)
Residential sector

ABSTRACT

The main objective of the present study is to apply the artificial neural network (ANN) methodology, linear regression (LR) and nonlinear regression (NLR) models to estimate the electricity consumptions of the residential and industrial sectors in Turkey. Installed capacity, gross electricity generation, population and total subscribership were selected as independent variables. Two different scenarios (powerful and poor) were proposed for prediction of the future electricity consumption. Obtained results of the LR, NLR and ANN models were also compared with each other as well as the projection of the Ministry of Energy and Natural Resources (MENR) and the results in literature. Results of the comparison showed that the performance values of the ANN method are better than the performance values of the LR and NLR models. According to the poor scenario and ANN model, Turkey's residential and industrial sector electricity consumptions will increase to value of 140.64 TWh and 124.85 TWh by 2015, respectively.
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1. Introduction

Turkey is located in the Northern Hemisphere at the junction of Europe and Asia. It has a land surface area of 774,815 km^2 officially. It is situated in Anatolia and South-Eastern Europe bordering the Black Sea, the Aegean Sea and the Mediterranean Sea. Thanks to its geographical position, it has an increasingly important role to play as an "energy corridor" between the major oil and natural gas producing countries in the Middle East, Caspian Sea and the Western energy markets [1–3]. Because of social and economic development of the country, the energy demand particularly for electricity is growing rapidly in Turkey [4,5]. According to the Turkish Statistics Institute (TUIK), Turkey's population has been increased by 7.6% from 2000 to 2009 [6]. As a developing country, Turkey's population is estimated to be over 100 million by the year of 2020 [7,8].

Energy is one of the most significant components in the developing countries. In Turkey, the growing population, industrialization and increasing living standards considerably increased the dependency on the imported energy. Consequently, in addition to the development of conventional energy resources, exploitation

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1364-0321/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2011.08.005

of non-conventional energy resources and energy conservation became inevitable [9,10]. Out of various energy sources, electric energy is considered to be a kind of energy source which can be used in various industrial applications and residence. In general, electricity is generated from hydro power, thermal and nuclear power plants [11]. Electricity is used in nearly all kinds of human activities, such as industrial production, residential purposes, agriculture, transportation, lighting and heating. Much of the growth in electricity consumption in Turkey has taken place in the residential sector since 1970. Although the amount of electricity consumed by the industrial sector has increased, its share in total electricity consumption decreased between 1970 and 2004. At present, residential sector is the biggest consumer of the electric energy in Turkey. Industrial sector comes second in this regard. The transportation and agriculture sectors are relatively small electricity consumers [12,13]. Turkey's net electricity consumption has increased at an average rate of 8.89% per year since 1975. While net electricity consumption was 13.50 TWh in 1975, it increased to 156.89 TWh in 2009. According to the Turkish government projections, an 8% annual growth rate is expected for the next 15 years. So, by the year 2020, the net electricity consumption will be the value of 434.57 TWh [14,15].

The estimation of electricity consumption is of great importance for the future electricity policies, such as conservation programs, the planning of capacity expansion and the construction of nationwide interconnection of power network [16]. Moreover, accurate prediction of electric energy demand is important for effective implementation and decision-making on capital-intensive investments. Turkey's energy forecasting studies are officially carried out by the Turkish Ministry of Energy and Natural Resources (MENR) using Model for Analysis of Energy Demand (MAED) simulation technique. MAED is used to forecast the medium and long term energy demands, considering the relationships between several factors that affect the social, economical and technological systems of the country [17].

2. Studies on forecasting energy demand in Turkey

In literature, various techniques are applied for energy demand forecasting of Turkey, such as degree-day, linear and multivariable regression, auto-regression, genetic algorithm, artificial neural networks, and Fuzzy logic method [18–21]. A summary of the studies on forecasting energy demand in Turkey between 2004 and 2011 is given in Table 1.

In 2004, Yumurtaci and Asmaz [22] forecasted the energy demand until 2050 using the statistical techniques. In their study, the projection of energy use of Turkey for the period of 1980–2050 is calculated based on the growth of population and energy consumption increase rates per capita. Multivariable regression model and first-order autoregressive time series modeling were used for natural gas demand by Gorucu and Gumrah [23], as well as Aras and Aras [24], respectively. Genetic algorithm model approach began to be used for forecasting energy and exergy consumptions by various authors such as Canyurt et al. [25], Ceylan and Ozturk [26], and Ozturk et al. [27]. Artificial neural network (ANN) technique was used for the natural gas demand of Turkey by Gorucu et al. [28]. In 2005, several versions of genetic algorithm methodology such as genetic algorithm transport energy demand estimation (GATEDE), genetic algorithm energy (GAEN), and genetic algorithm exergy (GAEX) were developed by Haldenbilen and Ceylan [29], and Ceylan et al. [30], respectively. Ozturk et al. [31] estimated electricity energy demand using genetic algorithm electricity demand model (GAELDM) and industrial electricity demand model (GAINELDM). In their study, the total and industrial sector electricity demands of Turkey are studied based on the gross national product (GNP), population, and import and export figures. Sozen et al. [32] modeled the net energy consumption (NEC) of Turkey using two different ANN models. In one of them, population, gross generation, installed capacity and year were used in the input layer of the network (Model 1). Other energy sources were used in the input layer of Model 2.

In 2006, genetic algorithm transport energy demand model (GATENDM) was developed by Canyurt et al. [33]. The GATENDM includes the parameters/indicators such as population, gross domestic product (GDP), import, export, car, bus, and truck sales. Murat and Ceylan [34] illustrated an artificial neural network (ANN) approach for the transport energy demand of Turkey. Ozturk et al. [35] estimated the total exergy input/output demand of Turkey using the genetic algorithm future total exergy input/output estimation models (GAFTEXIEM/GAFTEXOEM). Ediger et al. [36] developed a decision support system for forecasting fossil fuel production by applying a regression, autoregressive integrated moving average (ARIMA) and seasonal ARIMA (SARIMA) methods. Tunc et al. [37] developed a linear mathematical model to predict optimum future electric power supply investments of Turkey. In 2007, Sozen and Arcaklioglu [38] developed equations for estimating the consumption of the basic energy sources using ANN technique. Turkey's electricity consumptions on sectoral basis until 2020 were forecasted using artificial neural network (ANN) methodology by Hamzacebi [12]. Erdogdu [39] developed and used an ARIMA model to forecast net electricity consumption in Turkey. Akay and Atak [18] presented grey prediction with rolling mechanism (GPRM) approach to predict the Turkey's total and industrial electricity consumption. Ediger and Akar [19] used the autoregressive integrated moving average (ARIMA) and seasonal ARIMA (SARIMA) methods to estimate the primary energy demand of Turkey from 2005 to 2020. Toksari [40] developed an ant colony energy optimization energy demand estimation (ACOEDE) model for Turkey. Three different models were used to predict the net energy consumption of Turkey using ANNs by Sozen and Arcaklioglu [41]. The aim of their study was to obtain equations based on economic indicators (gross national product – GNP and gross domestic product – GDP) and population increase. In 2008, particle swarm optimization energy demand forecasting (PSOEDF) model was proposed by Unler [42]. The new increment ratio scenarios depending on both observed data and future predictions of population, energy consumption per capita and total energy consumption were developed to predict the hydro power potential and electric energy demand by Yuksek [43]. Yuksek [43] made a reevaluation by comparing and analyzing the results of 11 prediction model. In 2009, Sozen [44] obtained numerical equations to estimate Turkey's energy dependency based on basic energy indicators and sectoral energy consumption by using artificial neural network (ANN) technique. Kavaklioglu et al. [45] performed a study to develop ANN models for electricity consumption by using different input configurations as a function of economic indicators. Swan and Ugursal [46] studied an up-to-date review of the various modeling techniques used for modeling residential sector energy consumption. In 2010, Turkey's short-term gross annual electricity demand was forecasted by applying fuzzy logic methodology while general information was also given on economical, political and electricity market conditions of the country [20]. Cinar et al. [21] demonstrated an application of a hybrid model, improving the forward feeding back propagation model with genetic algorithm to forecast the annual hydroelectric generation. In 2011, Dilaver and Hunt [47] investigated the relationship between Turkish industrial electricity consumption, industrial value added and electricity prices to forecast future Turkish industrial electricity demand by applying the structural time series technique. Dilaver and Hunt [48] investigated the relationship between Turkish residential electricity consumption, household total final consumption

Table 1
A summary of the studies on forecasting energy demand in Turkey between 2004 and 2011.

Reference	Method	Forecasting for	Data	Forecasted years
[22]	Linear regression	Electric energy demand of Turkey	1980–2002	2003–2050
[23]	Multivariable regression model	Gas consumption for Ankara, Turkey	1991–2001	2002 and 2005
[24]	First order autoregressive time series model	Natural gas demand of Eskişehir, Turkey	1996–2001	Model is established
[25]	Genetic algorithm energy demand model (GAEDM)	Energy demand of Turkey	1970–2001	2002–2025
[26]	Genetic algorithm energy demand model (GAEDM)	Energy demand of Turkey	1970–2001	2002–2025
[27]	Genetic algorithm exergy consumption (GAPEX)	Petroleum exergy demand	1990–2000	2001–2020
[28]	Artificial neural network (ANN)	Gas consumption for Ankara, Turkey	1998–2001	2002 and 2005
[29]	Genetic algorithm transport energy demand estimation (GATEDE)	Transport energy demand of Turkey	1970–2000	2001–2020
[30]	Genetic algorithm energy (GAEN) and exergy (GAEX) estimating models	Energy and exergy consumption of Turkey	1990–2000	2001–2020
[31]	Genetic algorithm electricity demand model (GAELDM) and industrial electricity demand model (GAINELDM)	Total and industrial electricity energy demand of Turkey	1980–2001	2002–2020
[32]	Artificial neural network (ANN)	Net energy consumption (NEC) of Turkey	1975–2003	Model is established
[33]	Genetic algorithm transport energy demand model (GATENDM)	Transport energy demand of Turkey	1975–2002	2003–2020
[34]	Artificial neural network (ANN)	Transport energy demand of Turkey	1970–2001	2002–2020
[35]	Genetic algorithm future total exergy input/output estimation models (GAFTEXIEM/GAFTEXOEM)	Total exergy input/output demand of Turkey	1980–2002	2003–2023
[36]	Regression, autoregressive integrated moving average (ARIMA) and seasonal ARIMA (SARIMA) methods	Primary energy demand of Turkey	1950–2003	2004–2038
[37]	Linear mathematical model	Electric energy demand of Turkey	1980–2001	2004–2020
[38]	Artificial neural network (ANN)	Energy demand of Turkey	1975–2003	2004–2020
[12]	Artificial neural network (ANN)	Sectoral electricity energy demand of Turkey	1970–2004	2005–2020
[39]	Autoregressive integrated moving average (ARIMA) model	Electricity energy demand of Turkey	1984–2004	2005–2014
[18]	Grey prediction with rolling mechanism (GPRM) approach	Total and industrial electricity energy demand of Turkey	1970–2005	2006–2015
[19]	Autoregressive integrated moving average (ARIMA) and seasonal ARIMA (SARIMA) methods	Primary energy demand of Turkey	1950–2004	2005–2020
[40]	Ant colony optimization energy demand estimation (ACOEDE) model	Energy demand of Turkey	1979–2005	2006–2025
[41]	Artificial neural network (ANN)	Net energy consumption (NEC) of Turkey	1968–2005	Model is established
[42]	Particle swarm optimization energy demand forecasting (PSOEDF) model	Energy demand of Turkey	1979–2005	2006–2025
[43]	Model for Analysis of Energy Demand (MAED), Yumurtaci and Asmaz's model, Tunc, Camdali and Parmaksizoglu's model, Hamzacebi's model and TEIAS model	Hydro power potential and electric energy demand for Turkey	1975–2005	2010–2020
[44]	Artificial neural network (ANN)	Energy dependency of Turkey	1998–2006	2007–2020
[45]	Artificial neural network (ANN)	Turkey's electric consumption	1975–2006	2007–2025
[20]	Fuzzy logic method	Gross annual electricity demand	1975–2007	2008–2020
[21]	Forward feeding back propagation model with genetic algorithm	Hydroelectric energy	1970–2006	2007–2012
[47]	Underlying energy demand trend (UEDT) and structural time series model (STSM)	Industrial electricity demand for Turkey	1960–2008	2009–2020
[48]	Underlying energy demand trend (UEDT) and structural time series model (STSM)	Residential electricity demand for Turkey	1960–2008	2009–2020

expenditure and residential electricity prices by applying the structural time series model to annual data over the period from 1960 to 2008.

According to the previous results available in the literature, Turkey's energy forecasting studies were officially carried out by the MENR by using MAED simulation technique. In addition, various techniques such as linear and multivariable regression, auto-regression, genetic algorithm, grey prediction with rolling mechanism, ant colony model and artificial neural networks were also applied. In these applications, different independent variables were used for the energy demands of Turkey such as natural gas, petroleum, primary energy sources, transport energy, total, sectoral and industrial electricity energy. In the present study, electric energy demands of Turkey in the residential and industrial sectors were estimated. Linear regression (LR) and nonlinear regression (NLR) models and also artificial neural network (ANN) methodology were applied to analyze energy use and hence, conduct future projections. Electric energy demands were estimated based on the variables of installed capacity, gross electricity generation, population and total subscribership.

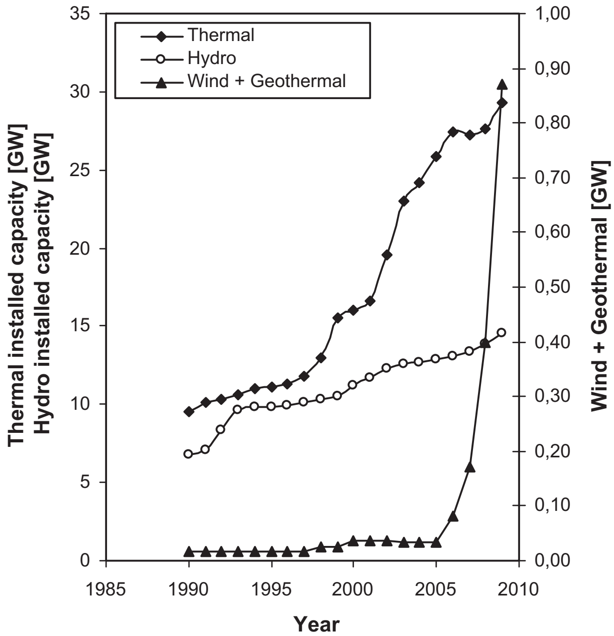

Fig. 1. The development of Turkey's installed capacity between 1990 and 2009 [51].

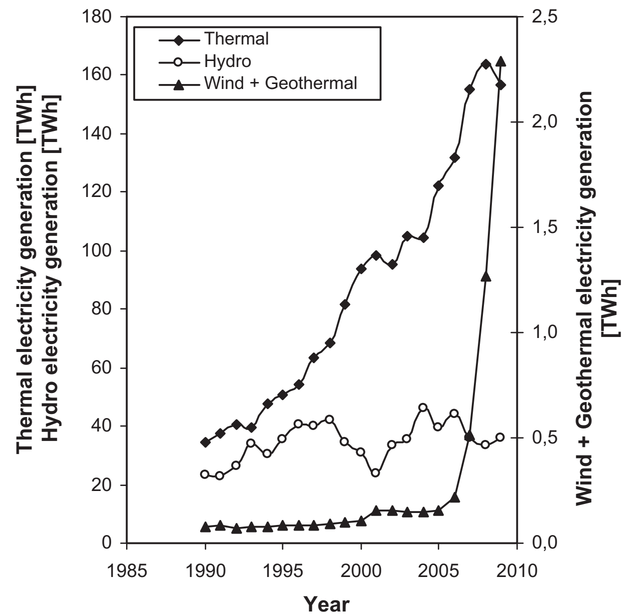

Fig. 2. The development of Turkey's electricity generation between 1990 and 2009 [51].

3. A review of electric energy in Turkey

Because Turkey does not have large fossil fuel reserves, it is presently an energy-importing country. Hard coal, oil and natural gas reserves in country except for lignite are limited. More than 70% of energy consumption in country is met by imported energy sources, and the share of imports grows each year continuously. Of the imported energy, 56% is used for the electricity production. The imported energy sources consist of oil, natural gas and hard coal. The amount of the imported oil is 50% (4.7 billion dollars) in total of imported energy sources and it is followed by natural gas with 40% (3.8 billion dollars) and hard coal with 10% (0.8 billion dollars) for the year 2003 [49]. Contribution of imported oil and gas is about 62% of Total Primary Energy Supply (TPES) of Turkey. The total amount of this imported oil and gas varies year to year, for example, it was 77% Total Primary Energy Supply (TPES) of Turkey in 2004 according to WEC-TNC report published in 2006 [50]. The total cost of imported energy sources such as oil, natural gas and hard coal is 33.8 and 33 billion dollars for 2007 and 2009, respectively. The amount of the imported energy sources is also 74% in 2009 [51]. These imported energy sources create financial problems in Turkey due to abovementioned reasons.

In Turkey, electricity is generated from the thermal, hydro, wind and geothermal power plants. But, there is no nuclear power used for electricity generation yet. The development of Turkey's installed capacity between 1990 and 2009 is presented in Fig. 1. The installed capacity of Turkey's electric power plants was 16.32 GW in 1990. In 1999, Turkey's installed electric power generation capacity reached 26.12 GW and 99.9% of its population was connected to the electricity grid [52,53]. In 2009, electricity installed capacity reached 44.76 GW. The share of thermal power plants accounted for 65.54% of this capacity (29.34 GW), while hydro power plants accounted for 32.50% (14.55 GW), geothermal and wind for 1.94% (0.87 GW).

The development of Turkey's electricity generation between 1990 and 2009 is illustrated in Fig. 2 [51]. As reported by the TEIAS, Turkey's gross electricity generation was 194.82 TWh in 2009. Of the total electricity generation, 80.36% comes from the thermal power plants, while 18.45% comes from the hydro power plants. In addition, the wind and geothermal power plants met 1.19% of Turkey's electric power generation. In this year, 156.56 TWh of this energy was produced by the thermal power plants. On the other hand, the annual electricity productions of the hydro power plants and the wind and geothermal power plants were 35.95 TWh and 2.29 TWh, respectively. According to the Chambers of Electrical Engineers, Turkey's electricity generation will be 400–500 billion kWh per year by year 2020 [5]. According to the prediction of Kenisarin et al. [54], the installed capacity of electric power plants is expected to reach 109.23 GW and the annual electricity production is going to be 623.84 TWh by 2025. In order to ensure a sustainable energy future in Turkey, various renewable energy options are explored in numerous studies [2,5,55–59].

The sectoral electricity consumption of Turkey between 1990 and 2009 is shown in Fig. 3 [15]. While net electricity consumption was 46.82 TWh in 1990, it increased to 156.90 TWh in 2009. For

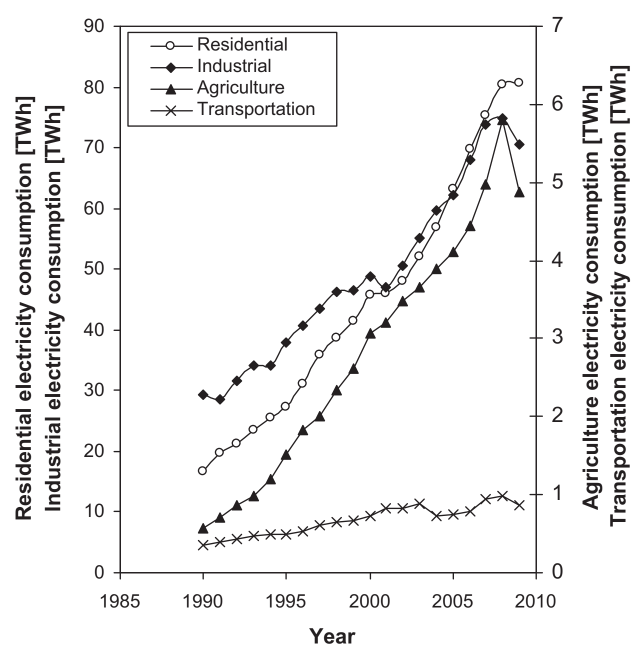

Fig. 3. The sectoral electricity consumption of Turkey between 1990 and 2009 [15].

Table 2
Correlation coefficients between the electricity consumptions and independent variables.

Variables	Residential electricity consumption	Industrial electricity consumption	Installed capacity	Gross electricity generation	Population	Total subscribership
Residential electricity consumption	1	0.99451	0.97752	0.99839	0.98636	0.98737
Industrial electricity consumption	0.99451	1	0.97007	0.99686	0.97770	0.97828
Installed capacity	0.97752	0.97007	1	0.97355	0.97352	0.97778
Gross electricity generation	0.99839	0.99686	0.97355	1	0.98929	0.98946
Population	0.98636	0.97770	0.97352	0.98929	1	0.99947
Total subscribership	0.98737	0.97828	0.97778	0.98946	0.99947	1

the total consumed electricity of 156.90 TWh, 80.68 TWh was used by residential sector, 70.47 TWh by industrial sector, 4.88 TWh by agriculture sector, and 0.87 TWh by transportation.

4. Materials and methods

4.1. Linear and nonlinear regression analyses

Regression analysis is one of the most widely used methodologies for expressing the dependence of a response variable on several independent variables [60]. The first step in regression analysis is to select independent variables for constructing a model. Here, the important peculiarity is; (1) to pick out adequate dependent variables, (2) to include linear relationship between dependent variable and independent variables, and (3) to include only relevant independent variables in the model. While dealing with large number of independent variables, it is of importance to determine the best combination of these variables to predict dependent variable according to Sahinler [61].

In linear regression, the function is a linear equation, i.e. straight-line, in the form:

$$Y = \beta_1 + \beta_2 X_1 + \beta_3 X_2 + \cdots + \beta_{n+1} X_n \tag{1}$$

where Y is the dependent variable, β_1–β_{n+1} are the equation parameters for the linear relation, and X_1–X_n are the independent variables for this system [62].

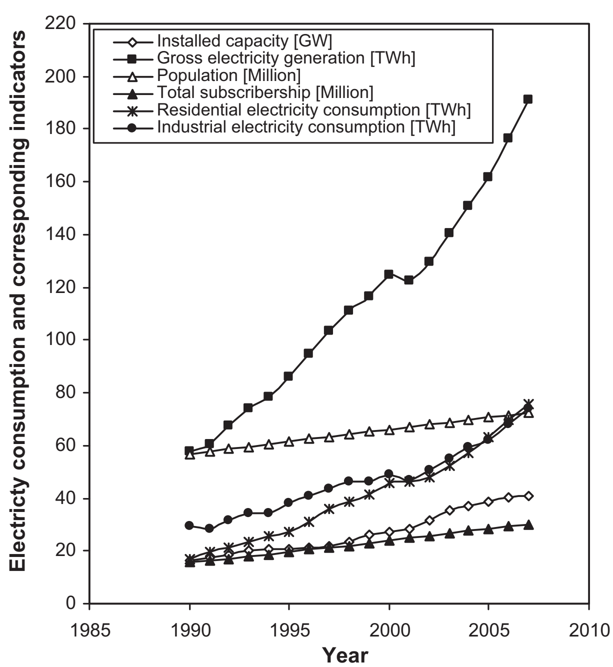

Fig. 4. Variations in electricity consumptions and predictor variables [6,15,51,73].

The general appearance of the nonlinear relation is assumed to be:

$$Y = \alpha_1 (X_1^{\alpha_2})(X_2^{\alpha_3}) \ldots (X_n^{\alpha_{n+1}}) \tag{2}$$

where α_1–α_{n+1} are the equation parameters for the nonlinear relation [62].

4.2. Artificial neural networks

Artificial neural networks (ANNs) are effective and reliable algorithms capable of performing functional input/output mappings. They are flexible mathematical structures capable of identifying complex non-linear relationships between input and output data sets. The main differences between various types of ANNs are the arrangement of network architecture. There are many methods to determine weights and functions for inputs and training [63,64]. Kalogirou [65] stated that there has been a substantial increase in the interest on the artificial neural networks during the past years. Studies successfully applied the ANN method in various fields of mathematics, engineering, medicine, economics, meteorology, psychology and neurology. The application of ANN method also includes the prediction of mineral exploration sites in electrical and thermal load predictions and in adaptive and robotic control and many other subjects. This method learns from given examples by constructing an input–output mapping in order to perform predictions [66]. In other words, to train and test a neural network, input data and corresponding output values are necessary [67]. ANNs can be trained to overcome the limitations of the conventional approaches to solve complex problems that are difficult to model analytically [68].

Fundamental processing element of a neural network is a neuron. The network usually consists of input layers, hidden layers and output layer [69]. A neuron j may be mathematically described with the following pair of equations [70];

$$u_j = \sum_{i=0}^{p} w_{ji} y_i \tag{3}$$

and

$$y_j = \varphi(u_j - \theta_j) \tag{4}$$

where p equals the number of source nodes in the input layer or neurons in the output layer. The artificial neuron receives a set of inputs or signals (y) with weight (w), calculates a weighted average of them (u) using the summation function and then uses some activation function (φ) to produce an output (y). The use of threshold (θ) has the effect of applying an affine transformation to the output (u) of the linear combiner. The sigmoid logistic non-linear function is described with the following equation;

$$\varphi(x) = \frac{1}{1 + e^{-x}} \tag{5}$$

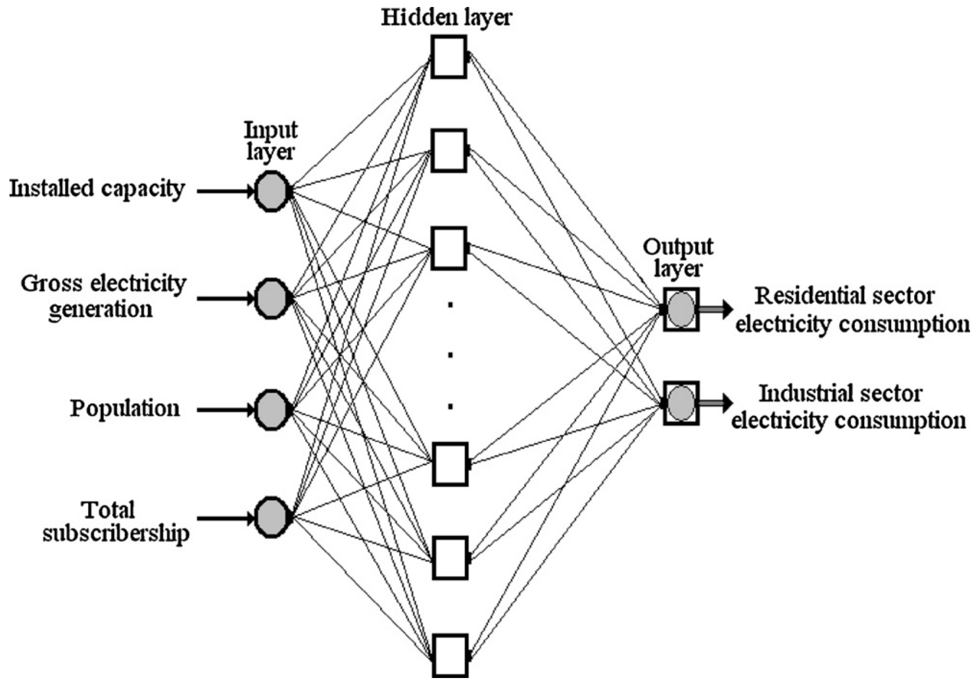

Fig. 5. ANN architecture.

5. Results and discussion

5.1. Selection of the predictor variables

In linear and nonlinear regression methods, the most significant point is to select the predictor variables that provide the best prediction equation for modeling of dependent variable. In addition, since the future predictor variables are unknown, the probability percentage of occurrence of these variables is substantially important. Furthermore, attention must be paid in selecting the independent variables. For this reason, the independent variables were initially selected based on correlation coefficient analysis. The correlation coefficients between the electricity consumptions and independent variables are given in Table 2. As seen from the table there is a high rate of correlation coefficient between variables. Secondly, those independent variables which were expected to be in the future year were investigated. For instance, installed capacity, gross electricity generation, population and total subscribership were selected as independent variables to obtain predictive equation for modeling of residential and industrial sector electricity consumptions. The variations of electricity consumptions and predictor variables are shown in Fig. 4.

5.2. Artificial neural network architecture

Artificial neural network architecture used in this study is shown in Fig. 5. Computer program was performed under MATLAB. The model is based on a feed-forward back-propagation (FFBP) network. Feed-forward networks often have one or more hidden layers of sigmoid neurons followed by an output layer of linear neurons. Installed capacity, gross electricity generation, population and total subscribership were used in the input layer of the network. On the other hand, residential and industrial sector electricity consumptions were used in the output layer of the network. After input and output variables were selected, the optimum number of neurons in the hidden layer was determined using the trial and error procedure by varying the number of hidden neurons from 2 to 16. By using trial and error method with different ANN configurations, it was decided to have the network consisting of one input layer with 4 neurons, one hidden layer with 8 neurons, and one output layer with 2 neurons. The maximum epoch's number was set to 300. The mean square error goal was set to 5×10^{-8}. Levenberg–Marquardt (LM) learning algorithm was used in the present simulation. Neurons in the input layer had no transfer function. Logistic sigmoid transfer function (logsig) and linear transfer function (purelin) were used in the hidden layer and output layer of the network as an activation function, respectively. In each layer, every neuron is connected to a neuron of adjacent layer having different weights. Each neuron as indicated in Fig. 5 receives signals from the neurons of the previous layer weighted by the interconnection values between neurons except input layer. Neurons then produce an output signal by passing the summed signal through an activation function [71]. An important stage of a neural network is the training step. During the training procedure, the input is presented to the network along with the desired output and the weights of the connections between neurons are adjusted in order to achieve the desired input/output relation of the network. This procedure goes on until the difference between the actual output of the network and the desired output is equal with a specified

Table 3
Turkey's installed capacity and gross electricity generation values for the period of 2008–2015 [51].

Year	Installed capacity (GW)		Gross electricity generation (TWh)	
	Powerful scenario[a]	Poor scenario[a]	Powerful scenario[a]	Poor scenario[a]
2008	42.43	42.23	212.18	211.65
2009	45.42	43.96	223.13	216.46
2010	51.57	44.47	250.37	221.49
2011	59.42	49.70	286.54	238.86
2012	66.69	55.59	333.87	278.74
2013	72.26	59.48	359.94	300.53
2014	78.22	63.51	387.61	318.56
2015	83.85	67.14	415.37	338.10

[a] Including existing, under construction, licensed power plants and new additional capacity.

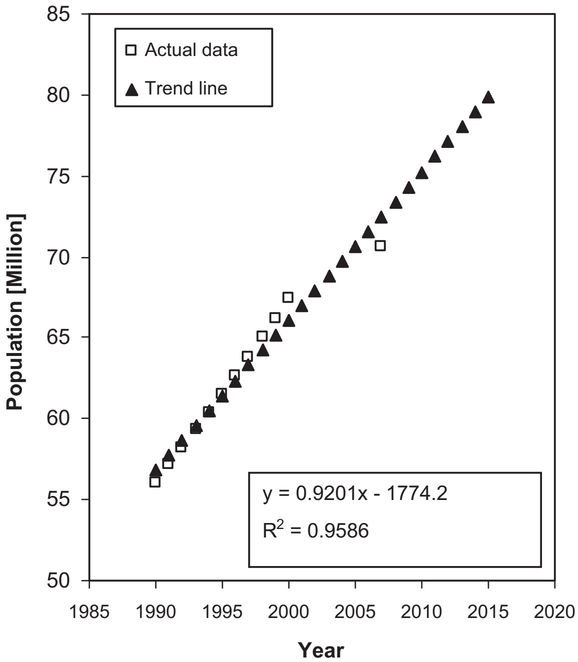

Fig. 6. Population and its corresponding fitted linear trends.

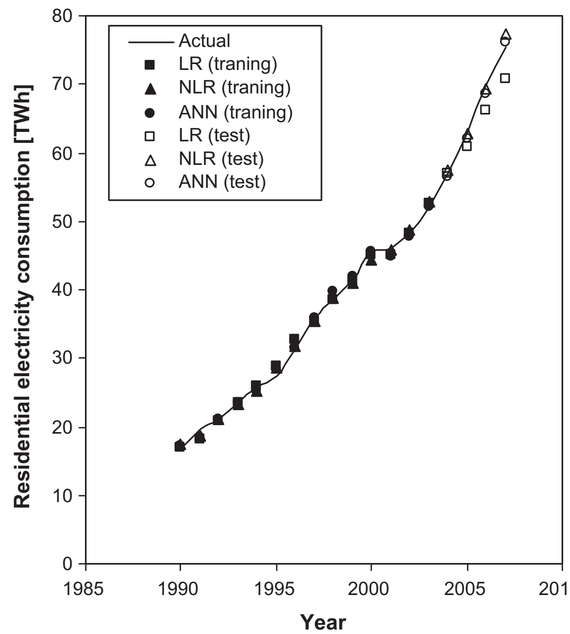

Fig. 8. Comparison of the residential sector electricity consumption between actual data and forecasting results.

remainder value. Here, the criterion is put forward as the network output which should be closer to the value of desired output [70,72].

5.3. Data used and future estimation of the predictor variables

Data from 1990 to 2003 were used for the training procedure. The data of four years (2004, 2005, 2006 and 2007) were used only as test data to confirm this method. Data were collected from different sources. Installed capacity and gross electricity generation data were taken from the Turkish Electricity Transmission Corporation (TEIAS) [51]. Population data were obtained from the Turkish Statistics Institute (TUIK) [6]. Total subscribership and electricity consumption data were also taken from the Turkish Electricity Distribution Corporation (TEDAS) [73] and the Turkish Ministry of Energy and Natural Resources (MENR) [15], respectively.

In order to conduct future projections for the period of 2008–2015, installed capacity and gross electricity generation values were taken from the Turkish Electricity Generation Capacity Projection, which was prepared by the Turkish Electricity Transmission Corporation (TEIAS). TEIAS [51] planned two scenarios both for demand and resource projections, called the Turkish Electricity Generation Capacity Projection. In this capacity projection study, Turkey's future installed capacity and gross electricity generation values are calculated by considering the existing power plants, other projects which are currently under construction and new

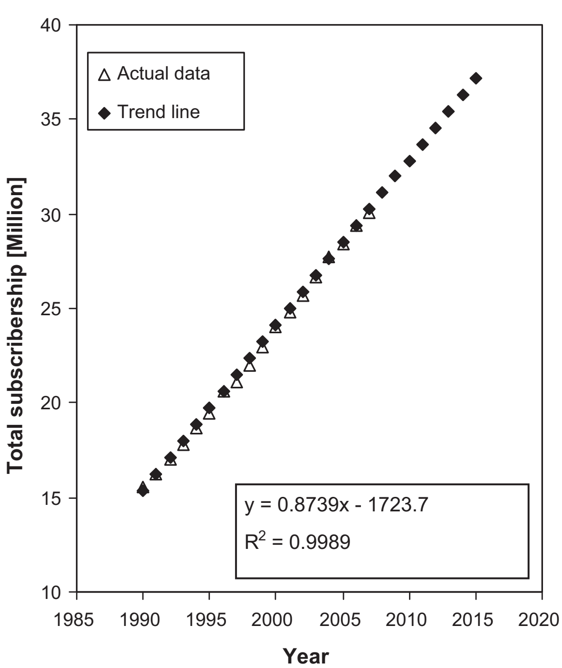

Fig. 7. Total subscribership and its corresponding fitted linear trends.

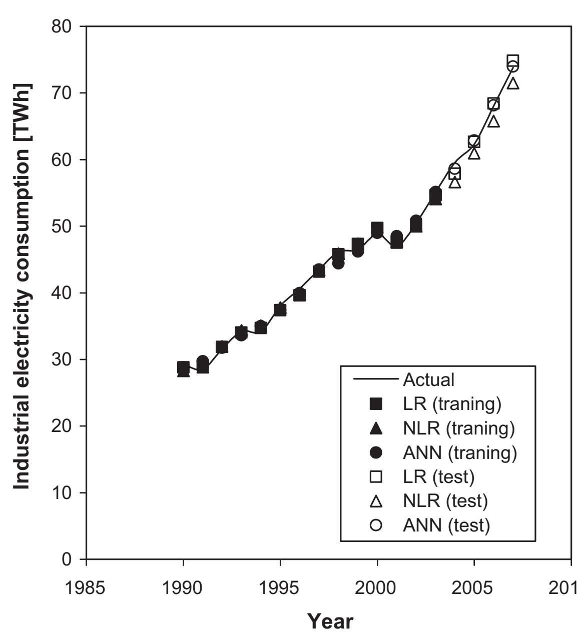

Fig. 9. Comparison of the industrial sector electricity consumption between actual data and forecasting results.

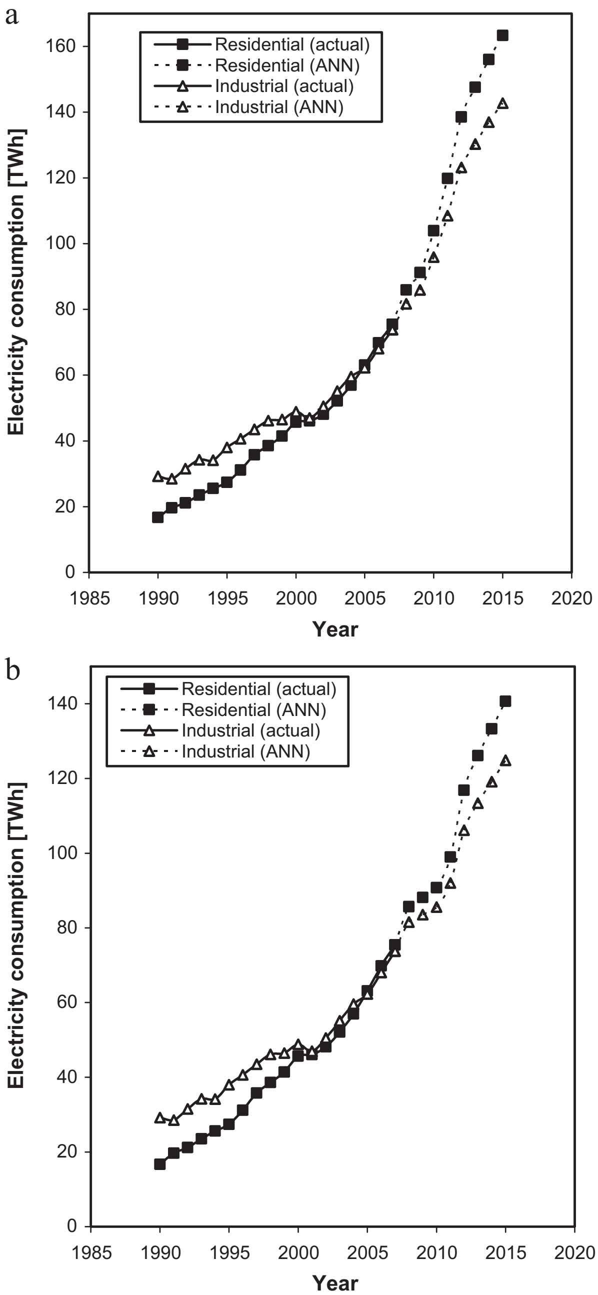

Fig. 10. Comparison of the electricity consumption between the residential and industrial sectors (a) for powerful scenario and (b) for poor scenario.

projects granted by license by the end of January 2008. Related data to the average and firm values for the next 10 years are obtained from the Electricity Generation Corporation (EUAŞ), Turkish Electricity Trade and Contracting Corporation (TEDAS) and General Directorate of State Hydraulic Works (DSI) for the existing and under construction thermal power plants and also hydro power plants. Data for new projects granted by license by the end of December 2007 were taken from the Energy Market Regulatory Authority (EPDK) and these data were updated according to “Progress Report of January 2008” published by the EPDK. While calculating generation capacities, the average generating values of hydro power plants under normal hydrologic conditions and firm generating values of hydro power plants under dry hydro conditions were considered separately.

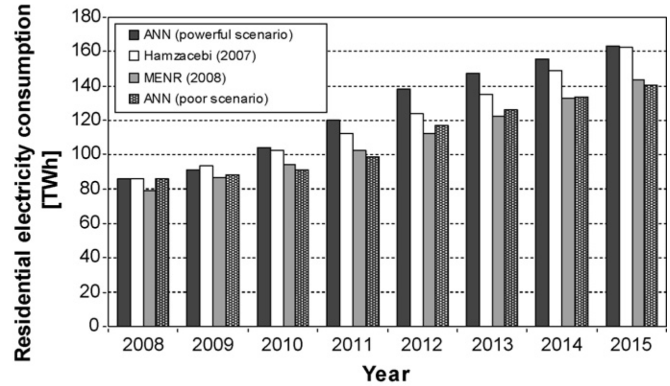

Fig. 11. Comparison of the residential electricity consumption between the present predictions and previous results.

According to the powerful scenario, in order to cover the energy demand, with the addition of 4319 MW capacity under construction, 12,818 MW capacity granted by license and expected to be in service on proposed date and also 26,173 MW capacity calculated by the long term generation expansion planning study adding to the existing system, hence, the total installed capacity and gross electricity generation will reach 83,845 MW and 415,369 GWh by the year 2015, respectively. On the other hand, according to the poor scenario, the total installed capacity and gross electricity generation are expected to be 67,135 MW and 338,098 GWh by the year 2015, respectively. Of the total installed capacity, 40,536 MW belongs to the existing power system, followed by the power plants under construction with 4329 MW capacity, other power plants granted by license and expected to be in service on proposed date with 8599 MW capacity and expected new power plants calculated by the long term generation expansion planning study with 13,682 MW capacity. According to this report, Turkey’s future installed capacity and gross electricity generation for the period of 2008–2015 are given in Table 3. In addition, population and total subscribership values for the period of 2008–2015 may be estimated with forms of mathematical expression such as linear trend line equation. They are shown in Figs. 6 and 7, respectively.

5.4. Results

Firstly, the training procedure was applied, and the LR, NLR and ANN models were obtained to get predictive equation. Secondly, the testing procedure was applied to evaluate the performance of the LR, NLR and ANN models. Comparisons of the residential

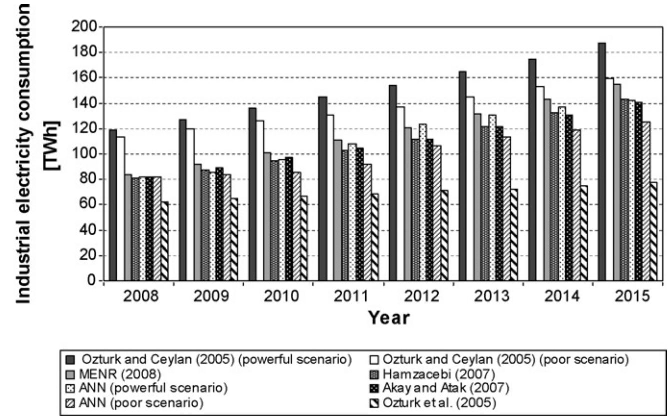

Fig. 12. Comparison of the industrial electricity consumption between the present predictions and previous results.

Table 4
Performance values (TWh) for residential electricity consumption in the testing procedure.

Year	Actual	LR	Relative error	NLR	Relative error	ANN	Relative error
2004	56.95	56.958	0.008	57.471	0.521	56.581	−0.369
2005	63.107	60.851	−2.256	62.888	−0.219	61.956	−1.151
2006	69.813	66.097	−3.716	69.274	−0.539	68.672	−1.141
2007	75.424	70.78	−4.644	77.22	1.796	76.079	0.655

Table 5
Performance values (TWh) for industrial electricity consumption in the testing procedure.

Year	Actual	LR	Relative error	NLR	Relative error	ANN	Relative error
2004	59.566	57.859	−1.707	56.623	−2.943	58.614	−0.952
2005	62.294	62.649	0.355	60.953	−1.341	62.85	0.556
2006	68.027	68.426	0.399	65.774	−2.253	68.143	0.116
2007	73.795	74.861	1.066	71.503	−2.292	73.98	0.185

Table 6
Future projections of residential sector electric energy demand (TWh).

Year	Powerful scenario			Poor scenario		
	LR	NLR	ANN	LR	NLR	ANN
2008	78.26	85.97	85.92	78.10	85.92	85.68
2009	82.44	91.95	91.24	80.45	90.74	88.16
2010	91.48	101.40	103.91	82.81	96.47	90.76
2011	103.17	112.92	119.86	88.94	103.86	98.96
2012	118.07	128.07	138.52	101.63	118.01	116.88
2013	126.74	138.75	147.53	108.99	128.24	126.12
2014	135.89	150.19	155.98	115.26	137.75	133.33
2015	145.06	162.34	163.32	121.96	148.39	140.64

Table 7
Future projections of industrial sector electric energy demand (TWh).

Year	Powerful scenario			Poor scenario		
	LR	NLR	ANN	LR	NLR	ANN
2008	83.55	78.33	81.74	83.25	78.07	81.54
2009	88.05	82.17	85.92	84.46	79.15	83.50
2010	101.25	93.32	95.91	85.52	80.05	85.55
2011	119.20	108.60	108.48	93.66	86.95	92.01
2012	142.55	128.52	123.19	113.04	103.03	106.13
2013	155.04	139.18	130.29	123.08	111.40	113.41
2014	168.41	150.62	136.95	131.28	118.28	119.10
2015	181.76	162.02	142.73	140.16	125.67	124.85

and industrial sector electricity consumptions between actual data and forecasting results are shown in Figs. 8 and 9, respectively. Comparisons showed a good agreement between the actual data and forecasting results. The performance values for electricity consumptions in the testing procedure are given in Tables 4 and 5. According to the results obtained, errors are within the acceptable limits. As seen in these tables, the performance values of the ANN method are better than the performance values of the LR and NLR models.

In order to conduct the future projections for the residential and industrial sector electricity consumptions using the LR, NLR and ANN methods, the parameters including installed capacity, gross electricity generation, population and total subscribership values were used for two scenarios. Forecast results obtained for the period of 2008–2015 are given in Tables 6 and 7. According to the ANN model prediction using the poor scenario, the total consumption of the residential sector is expected to be 140.64 TWh by 2015. On the other hand, the industrial sector electricity consumption will increase up to 124.85 TWh by the year 2015. In addition, according to the powerful scenario, this consumption is expected to be 142.73 TWh by the year 2015.

Comparison of the electricity consumption between the residential and industrial sectors is shown in Fig. 10. These sectors play an important role in economical decision making process in Turkey. At present, residential sector has the largest share of consumption among all the other sectors including industrial, agriculture and transportation and it is expected to continue growing due to the growth of population as well as social development.

In order to show performance of the present study, these projection results were compared with the similar studies in the published literature. For example, Figs. 11 and 12 show the comparisons of the residential and industrial sector electricity consumptions between the present study results and literature values, respectively. For the industrial sector, the ANN method based on the powerful scenario gives lower forecasts of energy demand compared to the predictions of MENR [15] and Ozturk and Ceylan [16]. On the other hand, for the residential sector, the ANN method gives higher forecasts of the energy demand than the data predicted by MENR [15]. The results obtained from the present study are consistent with the study of Hamzacebi [12].

6. Conclusion

In Turkey, there is no nuclear power plant constructed for electricity generation. Electricity is presently generated from the thermal, hydro, wind and geothermal power plants. Because Turkey

does not have large fossil fuel reserves, it is presently an energy-importing country. Coal, oil and natural gas reserves except for lignite are limited. But, Turkey has substantial reserves of renewable energy resources such as hydro, wind and solar sources. In this conjunction, renewable energy resources appear to be one of the most efficient and effective solutions as a clean and sustainable energy sources. So, Turkey should use available renewable energy sources as much as possible.

In this paper, LR, NLR and ANNs were applied to forecast the residential and industrial electricity consumptions to analyze energy use and perform future projections for the period 2008–2015. Turkey's residential and industrial sector electricity consumptions were 80.69 TWh and 70.47 TWh in 2009. These electricity consumptions may increase to 140.64 TWh and 124.85 TWh by the year 2015, respectively, according to the ANN model with poor scenario. It can be concluded that the ANN method is promising in forecasting the residential and industrial electricity consumptions depending on the variables of installed capacity, gross electricity generation, population and total subscribership.

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